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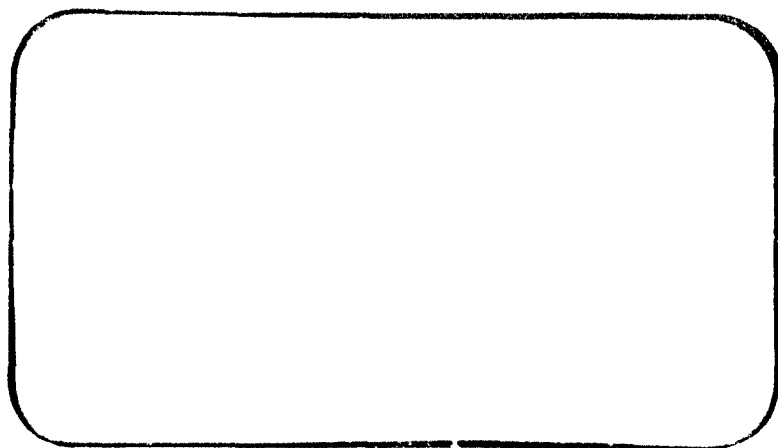
Effects of Notches and Saltwater  
Corrosion on the Flexural Fatigue  
Properties of Steels  
for Hydrospace Vehicles

Assignment 86 108  
MEL R&D Report 420/66  
October 1966

By  
M. R. Gross and  
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Effects of Notches and Saltwater Corrosion on the  
Flexural Fatigue Properties of Steels for Hydrospace Vehicles

by

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## ABSTRACT

✓ The flexural fatigue behavior of five constructional steels was investigated in air and salt water over a broad life spectrum ranging from 1000 to 100 million cycles. The yield strengths of the steels ranged from 40 to 200 thousand pounds per square inch (ksi). The effects of notches having theoretical stress concentrations ranging from 1.3 to 6 were included in this study. General conclusions are : (1) both mechanical notches and saltwater corrosion are more damaging in high-cycle fatigue; (2) the combined effect of mechanical notches and salt water is greater than either operating independently; and (3) the high-cycle saltwater corrosion-fatigue strengths of sharply notched low and intermediate alloy steels are less than 10 ksi beyond 10-million cycles, regardless of the tensile yield strength level. Additional conclusions relative to notch root radius, corrosion characteristics of the steels, and fatigue design curves are presented.

# EFFECTS OF NOTCHES AND SALTWATER CORROSION ON THE FLEXURAL FATIGUE PROPERTIES OF STEELS FOR HYDROSPACE VEHICLES

## Introduction

The operational capabilities of advanced types of sea-going vehicles, such as hydrofoils and deep submersibles, are limited to a great extent by the ability of structural materials to resist failure under severe operating conditions. The conventional strength properties of structural materials are continually being improved and the vehicle designer now has a choice among a number of materials having high strength-to-weight ratios, including steels, titanium alloys, aluminum alloys, and reinforced plastics. Before being given serious consideration, however, each material must be investigated to uncover susceptibilities to failure from extreme conditions imposed by higher operating speeds, greater operating depths, and the aggressive action of the saltwater environment.

Frequently, the higher operating stresses required in advanced applications, coupled with an increased sensitivity of many materials to structural defects and corrosion, introduce design considerations which heretofore were not particularly critical. One such consideration is the resistance of pressure-hull and underwater-foil materials to the simultaneous action of cyclic loads (fatigue) and corrosion. Since the fabricated structure will inevitably contain flaws, pores, or other

stress raisers, and will be exposed to attack by highly corrosive salt water, an investigation of the influence of notches and salt water on the fatigue properties of materials becomes important.

It is the purpose of this paper to present observations made in an investigation of the effect of mechanical notches and saltwater corrosion on the fatigue behavior of five structural steels over a broad life spectrum of 1000 to 100 million cycles.

#### Materials Investigated

The steels investigated are listed in Table 1, together with their chemical compositions and tensile properties. Brief descriptions of these steels are as follows:

HT Steel - This steel is a high-strength, low-alloy constructional steel used by the U. S. Navy for the pressure hulls of submarines constructed during World War II and early postwar period.

HY-80 Steel - This steel is a high-strength, notch-tough steel used by the U. S. Navy for pressure hulls of submarines constructed since about 1956.

HY-100 Steel - This steel is basically HY-80 steel upgraded in strength by lowering the tempering temperature.

Table 1 - Chemical Composition and Mechanical Properties

MEL Designation	Source of Material	Treatment	Chemical Composition, Weight %											Tensile Properties			
			C	Mn	S	P	Si	Cr	Ni	Mo	V	Al	Others	0.2 % YS, psi	TS, psi	Elong in 2 in. %	Reduction of area %
Material - RT																	
DSG	Portsmouth Naval Shipyard	As received	0.13	1.30	0.027	0.017	0.19	0.04	0.01	0.02	0.05	-	Ti-0.01 Cu-0.22	61,250	41,150	31	62
Material - HV-50																	
DQO	U. S. Steel	As received	0.14	0.28	0.019	0.015	0.29	1.53	0.34	0.42	-	-	-	104,600	87,650	28	72
DQT (RT)	U. S. Steel	HV-100 Re-tempered at 1200 F	0.15	0.21	0.020	0.013	0.20	1.72	0.37	0.41	-	-	-	103,000	89,700	26	62
DTZ (RT)	U. S. Steel	HV-100 Re-tempered at 1250 F	0.20	0.28	0.015	0.010	0.23	1.43	0.04	0.47	-	-	-	103,600	87,500	27	73
Material - HV-100																	
DTZ	U. S. Steel	As received	0.20	0.28	0.015	0.010	0.23	1.43	0.04	0.47	-	-	-	116,400	101,200	23	63
DQT	U. S. Steel	As received	0.17	0.22	0.020	0.013	0.20	1.76	0.04	0.43	-	-	-	122,300	103,200	21	65
DQC	Lukens	As received	0.17	0.31	0.027	0.003	0.22	1.51	0.01	0.43	-	-	-	120,250	105,300	23	66
Material - HV-130/150																	
DQC	Lukens	Heat treat from HV-100	0.17	0.31	0.027	0.003	0.22	1.51	0.01	0.43	-	-	-	160,300	151,800	16	57
5N	U. S. Steel	As received	0.10	0.73	0.004	0.004	0.26	0.53	4.37	0.54	0.07	0.017	-	147,000	141,000	21	71
DZH	U. S. Steel	As received	0.09	0.72	0.003	0.007	0.23	0.60	0.03	0.54	0.07	0.019	-	157,000	143,000	20	67
Material - Marage 150 (12Ni-5Cr-3Mo) Steel																	
EBS	U. S. Steel	Annealed & aged	0.026	0.044	0.010	0.003	0.022	4.47	12.10	2.37	-	0.33	Ti-0.2	202,200	197,000	16	57
YS = Yield Strength; TS = Tensile Strength; Elong = Elongation																	

HY-130/150 - This steel is currently under development as a high-strength, notch-tough steel for applications requiring higher strength-to-weight ratios than obtainable with HY-80 steel. It is the material which will be used in the pressure capsule of the prototype Deep Sea Rescue Vessel.

Marage 180 - Maraging steels are high-strength steels which obtain their strength by the precipitation of intermetallic compounds in a low-carbon, iron-nickel martensitic matrix. At present, these steels have had no general application in sea-water structures, but are potentially useful in this area.

#### Method of Test

Two general types of flexural fatigue specimens were used in this investigation. High-cycle fatigue tests were performed with rotating cantilever-beam specimens having the various dimensions shown in Figure 1. These were constant-stress (deadweight load) tests with a frequency of 1450 cpm. The smooth specimens (Item a, Figure 1) were circumferentially and longitudinally polished to a metallographic finish.

Low-cycle fatigue tests were performed with equipment described previously.<sup>1</sup> Flat flexure-type specimens having the dimensions shown in Figure 2 were used. The short end of the specimen was held stationary, while the long end was flexed

<sup>1</sup>Superscripts refer to similarly numbered entries in the references at the end of the text.

between electrical or mechanical stops by a hydraulic piston. One or more strain gages (0.25-inch gage length) were attached to the minimum test section to record the longitudinal strain. It should be noted in Figure 2 that the placement of gages on the notched specimens was such as to give a nominal strain, irrespective of the notch.

All of the fatigue tests were of the completely reversed type (fatigue ratio = -1). The low-cycle fatigue tests in air were cycled at 1 cpm using electrical stops. This produced saw-tooth strain-time pattern. In the low-cycle corrosion-fatigue tests, the specimens were cycled at various rates ranging from 0.02 to 0.2 cpm using mechanical stops and timers. This produced square-wave patterns having dwell times ranging from about 0.1 to 25 minutes. Subsequent analysis showed no significant effect for cycling rates over the range of frequencies studied. Accordingly, the corrosion-fatigue data in this paper have been analyzed independent of cycling rate.

In the corrosion-fatigue tests, Severn River water continuously wetted the test surface. Application was such that the water applied was well aerated. Severn River water is a brackish estuary water containing  $1/6$  to  $1/3$  the salt content of natural seawater depending on the season and the tide. Previous fatigue tests in both Severn River water and natural seawater have shown no significant differences in the effects of the two

media. In the case of the low-cycle corrosion-fatigue tests, the specimens were first cycled in air until stress-strain conditions stabilized (approximately 10 cycles). After recording the total strain range, the strain gage was removed and the test was continued in the presence of salt water.

#### Failure Criteria

Failure in the high-cycle, rotating cantilever-beam tests consisted of complete fracture. Failure in the low-cycle smooth-specimen tests was defined as one or more surface cracks,  $3/16$  to  $1/4$  inch in length. In the notched specimens, failure was defined as one or more surface cracks  $1/8$  to  $3/16$  inch in length, extending from the ends of the notch.

#### Stress Concentration Factors

The theoretical stress concentration factors for the notched fatigue specimens were determined from tables and graphs derived by Neuber. The case of the centrally located surface notch in the low-cycle fatigue specimens is not covered by Neuber. It was assumed, however, that the results would be similar to the case of the full-width surface notch.

#### Stress Calculations

There is general agreement that low- and intermediate-cycle fatigue life is dependent on total strain range.<sup>1,2,3</sup> Accordingly, the total strain range for each low cycle fatigue specimen was determined from the strain gage attached to the test section after conditions became stabilized. The total strain range was

then converted to a reversed pseudoelastic stress (a fictitious elastic stress) by the following relationship

$$S_{PE} = \frac{E}{2} (\Delta e_T) \quad \dots\dots(1)$$

where

$S_{PE}$  = reversed pseudoelastic stress, psi

$E$  = modulus of elasticity, psi

$\Delta e_T$  = total strain range, in/in.

In the case of the high-cycle fatigue tests, the maximum nominal reversed stress was calculated from the applied dead-weight load and the dimensions of the specimen, disregarding notch effects. The nominal stress and pseudoelastic stress are assumed to be the same in the high-cycle tests since the behavior of the specimen is essentially elastic.

#### road Life Spectrum Fatigue Curves

The combined high- and low-cycle fatigue data for each material and test condition were plotted on the basis of pseudoelastic stress,  $S_{PE}$ , versus cycles to failure,  $N$ . Curves or lines of best fit were calculated for each set of data in either of two forms, whichever gave the best correlation for the input data

$$S_{PE} = CN^{-k} , \quad \dots\dots(2)$$

r

$$S_{PE} = mN^{-n} + S_E \quad \dots\dots(3)$$

where

$N$  = cycles to failure

$S_E$  = fatigue limit, psi

$c, k, m, n$  = regressions constants.

Equation (2) is a power function giving a linear relation on a log-log plot. Equation (3) is taken from Langer<sup>3</sup> and takes into account this leveling-off of data in the high-cycle region as occurs in the development of a fatigue limit.

#### Results of Tests

Figures 3 and 4 are the  $S_{PE}$  versus  $N$  curves for the HY-100 steel in air and saltwater environments, respectively. These curves are typical of the fatigue behavior observed for the various steels. Since curves for the other four steels were similar, they have not been included in the paper.

Included in Figures 3 and 4 is a low-cycle fatigue "design curve" based on the best-fit, smooth-air curve and having a reduction factor of either 2 on stress or 20 on life, whichever is more conservative at each point. It is Langer's<sup>2</sup> belief that these reduction factors are sufficient to cover the effects of size, environment, surface finish, and scatter of data. Stress concentrations are given separate consideration. With respect to environment, Section III of the ASME Boiler and Pressure Vessel Code requires that separate consideration be given to the effects of "unusually corrosive environments."

Table 2 is a summary of the fatigue properties for each material and test condition where the fatigue strength reduction factors,  $K_f$ , are based on smooth specimens run in air at the indicated life. It is apparent in Table 2 and Figure 3 that the fatigue strength reduction factors in air for HY-100 steel at  $K_t = 4.5$  to 6, are less than for those at  $K_t = 3$ . This is also true for HT steel, and presumably would have been true for HY-80 steel if the higher stress concentrations had been run.

These results indicate that there is a critical notch radius, greater than zero, which gives maximum fatigue strength reduction factors. Such a conclusion has support both in theory and experiment.<sup>4,5</sup> For a given type of notch, the critical radius is dependent on strength and grain size. For the higher-strength HY-130/150 and Marage 180 steels, it appears that the critical radius is at or below 0.002 inch.

Figures 5, 6 and 7 summarize the individual and combined effects of notches and saltwater corrosion on the five steels. Figure 5 compares the most damaging notch with the smooth air-test data. It is apparent that the damaging effects are larger at the high-cycle end of the spectrum. Figure 6 compares the effects of salt water on smooth specimens. Once again, the high-cycle effects are the largest. Figure 7 compares the

Table 2 - Summary of Fatigue Properties

Material	Condition	Environment	Fatigue Strength Pseudoelastic Stress, ksi					Fatigue Strength Reduction Factor K <sub>f</sub>				
			N=10 <sup>6</sup>	N=10 <sup>7</sup>	N=10 <sup>8</sup>	N=10 <sup>9</sup>	N=10 <sup>10</sup>	N=10 <sup>6</sup>	N=10 <sup>7</sup>	N=10 <sup>8</sup>	N=10 <sup>9</sup>	N=10 <sup>10</sup>
HT Steel	Smooth	Air	336.0	96.0	47.4	37.5	35.1	1.00	1.00	1.00	1.00	1.00
	Notch K <sub>t</sub> =1.3	Air	230.0	91.2	42.2	29.5	25.3	1.20	1.05	1.12	1.27	1.33
	Notch K <sub>t</sub> =3	Air	177.6	63.8	32.8	21.1	16.1	1.87	1.40	1.44	1.78	2.18
	Notch K <sub>t</sub> =4.5-6	Air	192.1	76.2	40.6	28.6	23.2	1.75	1.26	1.17	1.31	1.51
	Smooth	Salt Water	No Data Available		47.0	27.3	6.2	-	-	1.01	1.37	5.66
	Notch K <sub>t</sub> =1.3	Salt Water	120.6	63.5	39.5	23.0	7.5	2.73	1.40	1.20	1.63	4.62
	Notch K <sub>t</sub> =3	Salt Water	74.6	48.0	30.1	19.3	7.7	4.50	2.00	1.58	1.94	4.56
	Notch K <sub>t</sub> =4.5-6	Salt Water	80.8	50.0	30.5	18.8	7.1	4.19	1.92	1.55	2.00	4.94
HY-80	Smooth	Air	231.5	113.6	69.3	50.9	41.6	1.00	1.00	1.00	1.00	1.00
	Notch K <sub>t</sub> =3	Air	176.6	70.5	36.3	25.2	20.5	1.31	1.61	1.88	2.02	2.03
	Smooth	Salt Water	207.0	100.0	47.4	25.2	8.3	1.12	1.13	1.38	2.02	4.74
	Notch K <sub>t</sub> =3	Salt Water	151.4	71.0	33.8	16.0	3.6	1.53	1.60	2.02	3.13	11.55
HY-100	Smooth	Air	229.3	120.0	83.3	71.4	65.7	1.00	1.00	1.00	1.00	1.00
	Notch K <sub>t</sub> =1.3	Air	132.5	122.2	66.4	50.4	40.1	1.24	1.17	1.26	1.42	1.64
	Notch K <sub>t</sub> =3	Air	191.0	79.3	39.9	23.8	16.2	1.13	1.50	2.16	3.00	4.05
	Notch K <sub>t</sub> =4.5-6	Air	225.0	84.0	45.3	34.3	30.4	1.01	1.43	1.85	2.08	2.16
	Smooth	Salt Water	192.3	77.3	50.3	23.1	11.6	1.17	1.23	1.65	2.54	5.66
	Notch K <sub>t</sub> =1.3	Salt Water	162.3	83.0	47.2	25.4	7.4	1.39	1.37	1.78	2.81	3.87
	Notch K <sub>t</sub> =3	Salt Water	169.7	81.6	37.2	18.8	4.3	1.33	1.47	2.14	3.80	15.29
	Notch K <sub>t</sub> =4.5-6	Salt Water	140.0	75.1	40.2	21.6	6.2	1.61	1.60	2.08	3.31	10.60
HY-130/150	Smooth	Air	222.8	132.3	74.1	77.5	67.3	1.00	1.00	1.00	1.00	1.00
	Notch K <sub>t</sub> =1.3	Air	207.2	120.2	81.3	64.0	52.3	1.03	1.10	1.16	1.21	1.27
	Notch K <sub>t</sub> =3	Air	249.8	72.2	54.4	45.4	42.7	0.83	1.44	1.73	1.71	1.57
	Notch K <sub>t</sub> =6	Air	458.0	80.0	44.0	40.4	40.0	0.48	1.66	2.14	1.92	1.68
	Smooth	Salt Water	233.5	124.0	64.7	34.1	3.2	0.34	1.07	1.45	2.27	7.32
	Notch K <sub>t</sub> =1.3	Salt Water	174.5	101.0	52.6	27.7	7.4	1.14	1.31	1.79	2.80	9.10
	Notch K <sub>t</sub> =6	Salt Water	201.4	83.0	39.3	17.8	3.5	1.11	1.51	2.36	4.35	19.20
	Smooth	Air	243.9	158.7	115.2	93.1	76.0	1.00	1.00	1.00	1.00	1.00
Marage 130	Notch K <sub>t</sub> =1.3	Air	225.6	125.0	83.7	61.3	57.0	1.03	1.27	1.38	1.39	1.33
	Notch K <sub>t</sub> =3	Air	190.4	124.9	57.9	71.3	56.0	1.23	1.27	1.28	1.30	1.36
	Notch K <sub>t</sub> =6	Air	258.0	92.9	47.4	34.8	30.4	0.35	1.71	2.44	2.68	2.50
	Smooth	Salt Water	152.3	93.6	53.5	37.4	17.3	1.50	1.70	1.97	2.49	4.39
	Notch K <sub>t</sub> =1.3	Salt Water	142.5	89.6	57.9	33.8	20.4	1.71	1.77	1.99	2.40	3.72
	Notch K <sub>t</sub> =6	Salt Water	112.5	63.7	36.3	21.0	7.6	2.16	2.49	3.18	4.44	10.00

combined effect of both notches and salt water. Two observations appear to be significant. First, the difference in the low-cycle fatigue results are greater than when the factors were considered individually. Second, the fatigue strength range between the five steels has been reduced to 4 ksi at 100-million cycles.

Figure 8 shows, in greater detail, the high-cycle effects with respect to the theoretical stress concentration factor. The minimum strengths at  $K_t = 3$ , mentioned previously for HT and HY-100 steels tested in air, are readily apparent.

Figures 9 and 10 show the trend of the strength reduction factors,  $K_f$ , in Table 2 for the lowest- and highest-strength steels investigated. In Figure 9 the notch sensitivity of HT steel in air is low over a broad range of life, the highest strength reduction factor observed being approximately 2. In the presence of salt water, however, substantial increases in notched-strength reduction factors occurred in HT steel at both ends of the life spectrum. In the absence of a notch, only the high-cycle strength reduction factors were affected. Comparison of notched and unnotched corrosion fatigue data indicates that the notch intensifies the corrosion attack in the low-cycle region, but the attack is more general and independent of the notch in the high-cycle region.

Figure 10 is typical of the response observed for the other four steels. The combined action of notches and salt water in the low-cycle region was not as severe as for HT steel. On the other hand, sharp notches tended to intensify the corrosion effect in the high-cycle region. The magnitude of this effect generally increased with increasing strength level of the steel.

The design curves described previously are included in Figures 9 and 10. Noteworthy in Figure 9 is the fact that the design curve is sufficiently conservative to include the effects of both notches and environment up to the lives of 1 million cycles. In Figure 10, however, the design curve does not include either the effect the effect of sharp notches beyond about 10,000 cycles or the broad effects of environment. One would conclude, therefore, that both notches and the saltwater environment should be treated separately in high-strength steels, and that salt water should be considered as an "unusually corrosive environment" when such steels are being applied in accordance with Section III of the Boiler and Pressure Vessel Code. •

Figures 11 through 13 are enlarged views of the test sections of corrosive-fatigue specimens. Item a, Figure 11 shows the general corrosive attack of HT steel which has almost obliterated the mild notch,  $K_t = 1.3$ , after 10 days' exposure. This same type of attack has blunted the sharp notch,  $K_t = 6$ , of the

lower stressed specimen. Item b, Figure 11, which was removed from test after a 1-year exposure.

Figure 12 shows the general corrosion of HY-130/150 steel to be less severe than that of HT steel, and that fatigue crack initiation in the low-cycle region is primarily dictated by the notch.

The high propensity of 12-percent Ni maraging steels to localized pitting, even with short exposure times, is evident in Figure 13. Although mechanical notches are the determining factor in establishing the location of primary crack initiation in the notched specimens, it is evident that the corrosion pits dictate the course of crack propagation by acting as local crack-initiation sites. These local cracks in turn tend to link together to form major crack paths. The detrimental effect of pitting on the low-cycle corrosion-fatigue strength of the maraging steel is evident in the high strength reduction factors observed for the smooth specimens (see Table 2 and Figure 10).

### Conclusions

Broad life spectrum flexural fatigue tests on five steels (HT, HY-80, HY-100, HY-130/150, and Marage 180) resulted in the following conclusions:

- Both mechanical notches and saltwater corrosion are more damaging in high-cycle than in low-cycle fatigue.

● The combined effect of mechanical notches and salt water is greater than either operating independently.

● The critical notch root radius in high-cycle fatigue for HT, HY-100 and presumably HY-80, is approximately 0.010 inch. The critical radius for HY-130/150 and Marage 180 is at or below 0.002 inch.

● The high-cycle, saltwater corrosion-fatigue strengths of sharply notched low and intermediate alloy steels are less than 10 ksi beyond 10-million cycles, regardless of tensile yield strength level.

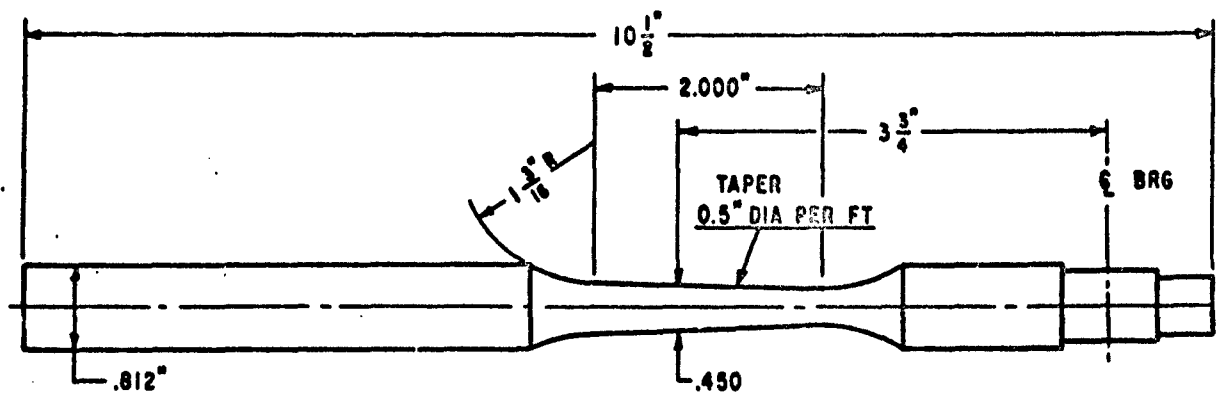
● The corrosion characteristics of the steel have an effect on fatigue behavior. For example, the general corrosion susceptibility of HT steel diminishes the effect of sharp notches in the high-cycle region. On the other hand, the propensity of 12-percent Ni, Marage 180 for localized pitting, intensifies notch effects and generates crack sites which affect crack initiation and propagation.

● A low-cycle fatigue "design curve," based on reduction factors of 20 on life, or 2 on strength, is conservative up to 1 million cycles for HT and HY-80 steel in the presence of either sharp notches or saltwater environment. In the presence of both, it is conservative only for HT steel. This leads to

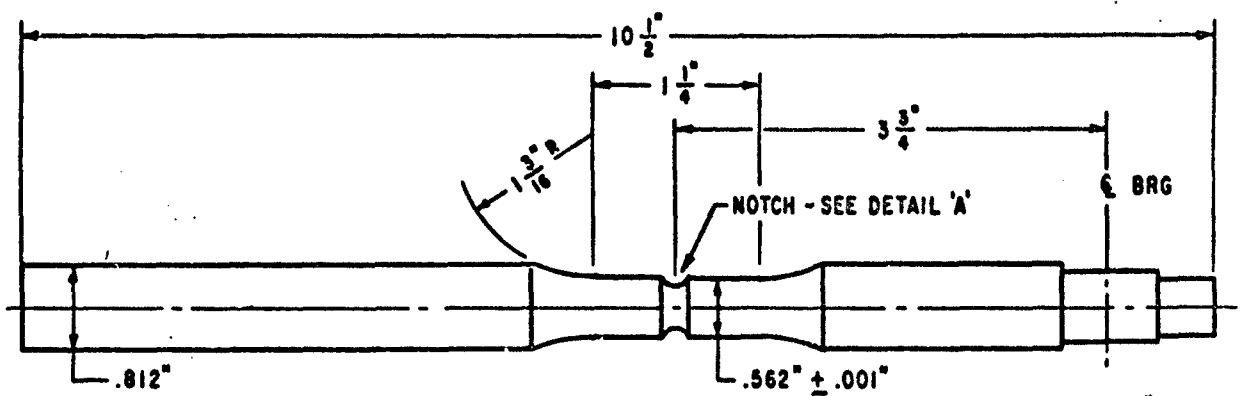
the conclusion that both notches and saltwater environment should be given consideration apart from such a design curve in high-strength steels.

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(a) SMOOTH SPECIMEN



(b) U-NOTCH SPECIMEN ( $K_t \sim 1.3$ )

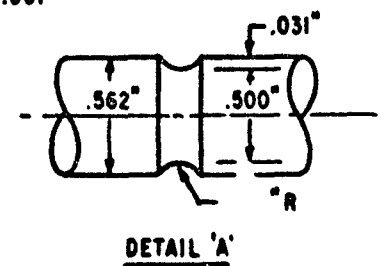
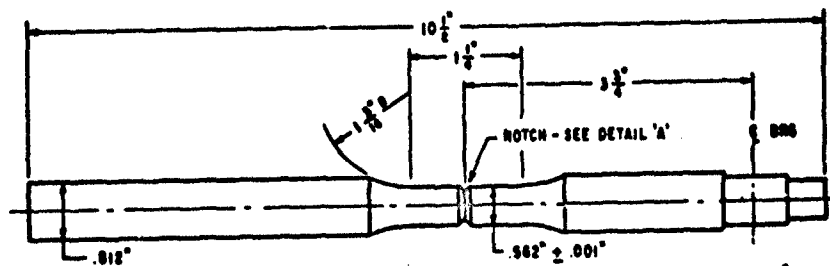
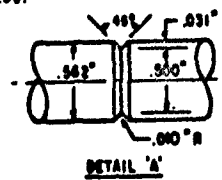


Figure 1  
Rotating Beam Fatigue Specimens



(c) V-NOTCH SPECIMEN ( $K_1 \sim 3$ )



(d) V-NOTCH SPECIMEN ( $K_1 \sim 6$ )

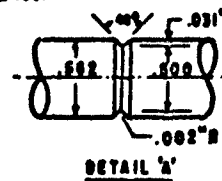


Figure 1 (Cont.)

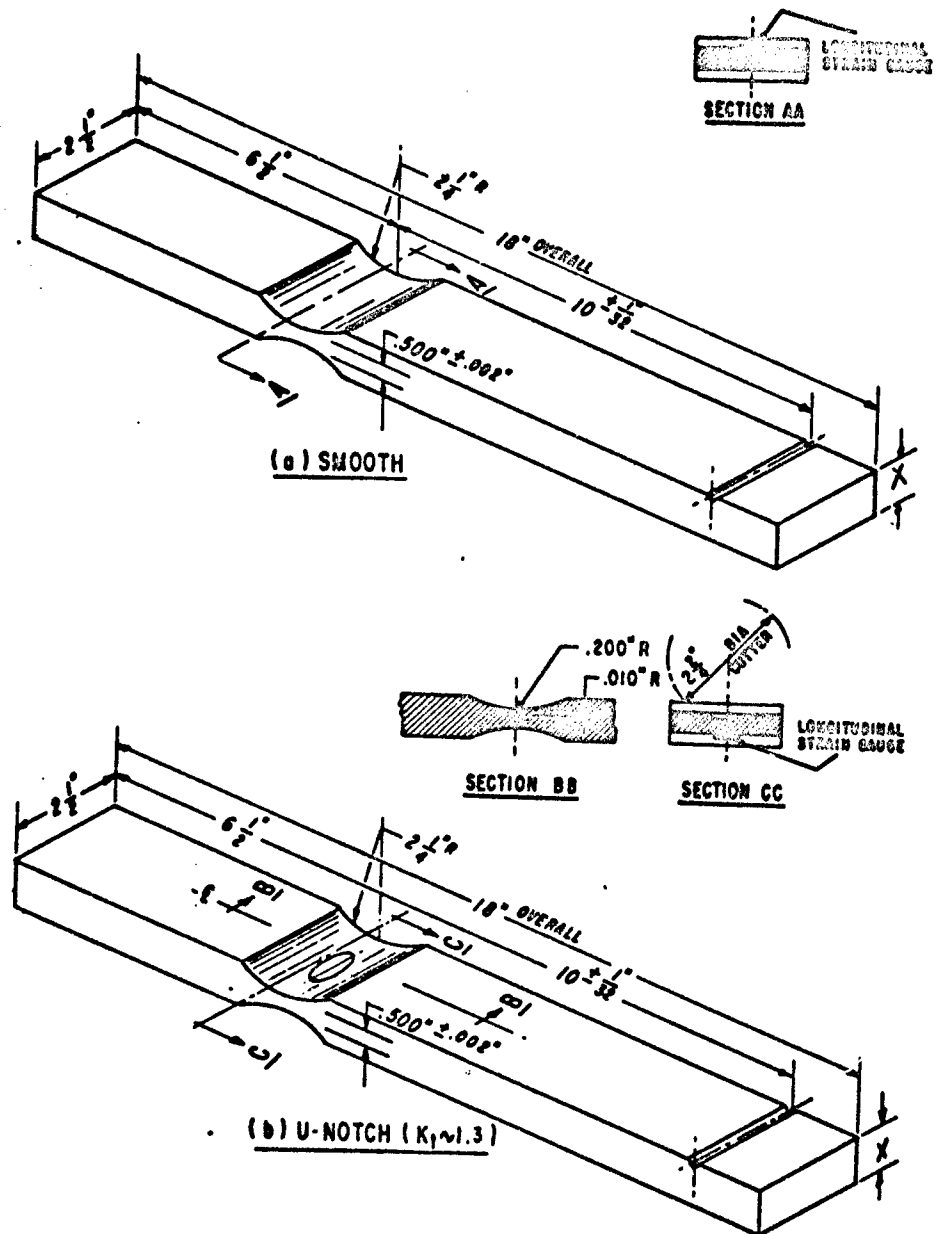


Figure 2  
Plastic Strain Fatigue Specimens

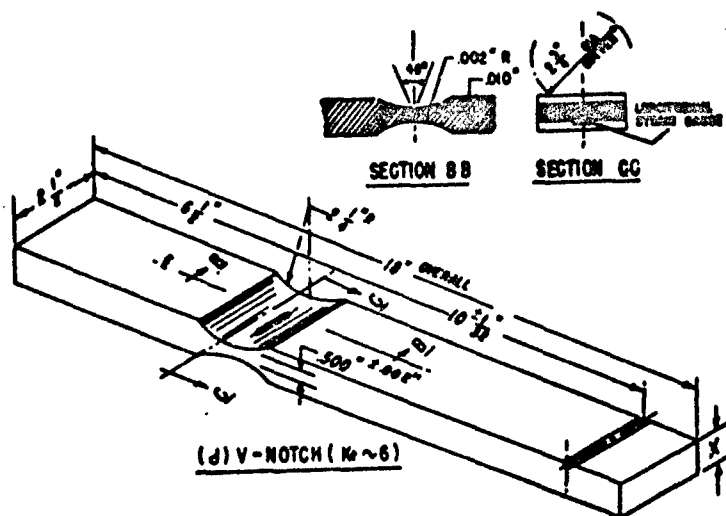
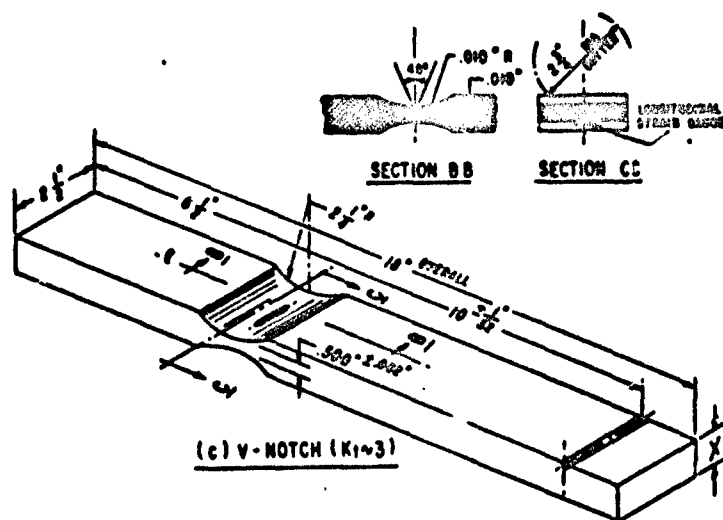


Figure 2 (Cont.)

Figure 3  
Flexural Fatigue Curves, HY-100 Steel, Air Environment

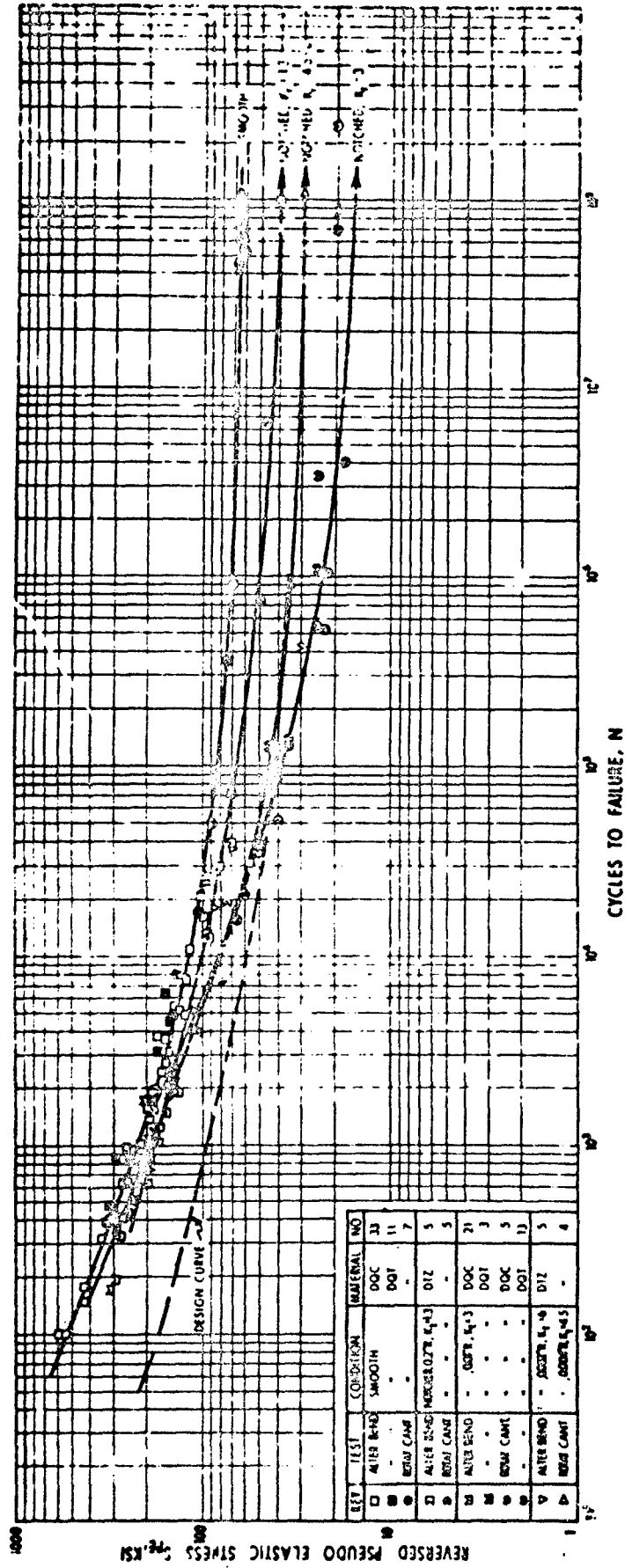


Figure 4  
Flexural Fatigue Curves, HY-100 Steel, Saltwater Environment

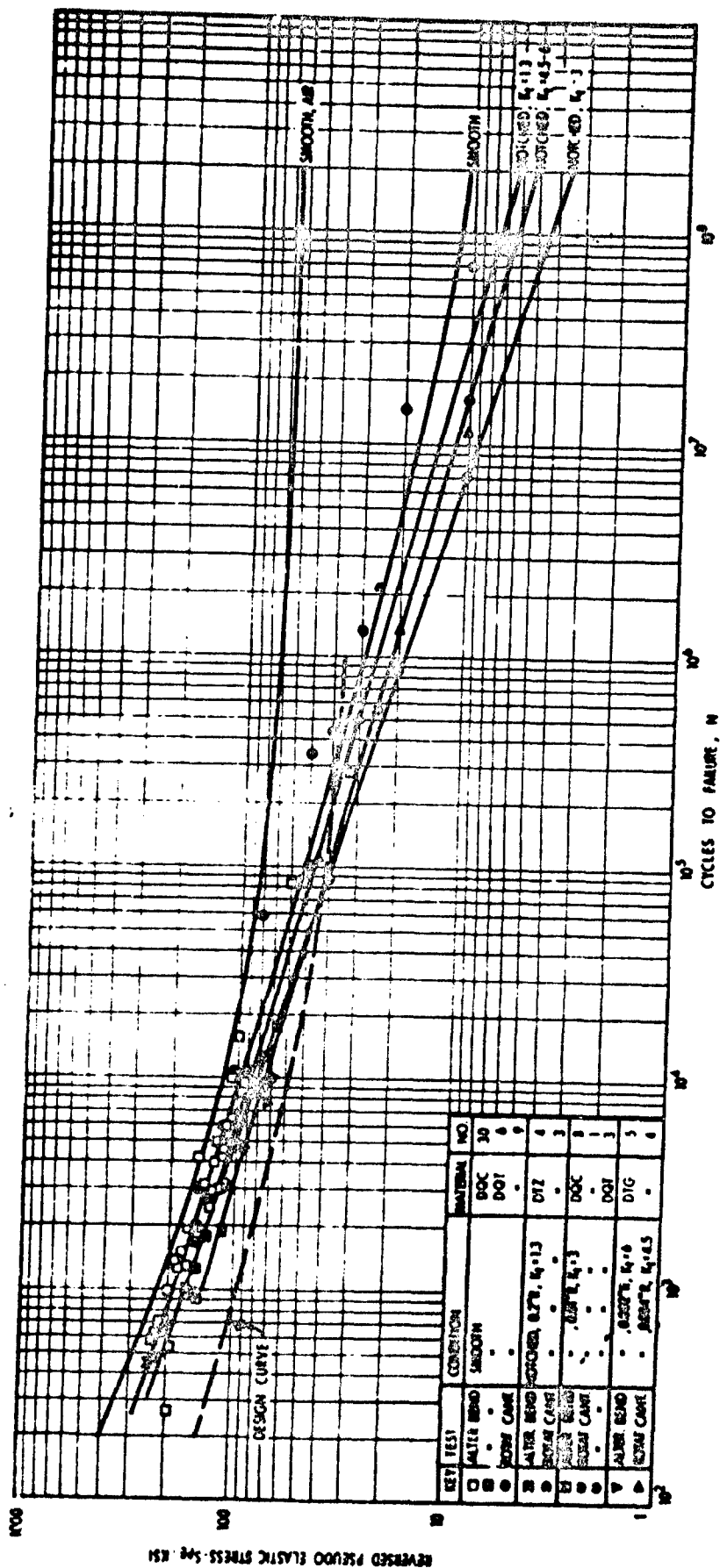


Figure 5  
Effect of Sharp Notches on Steels

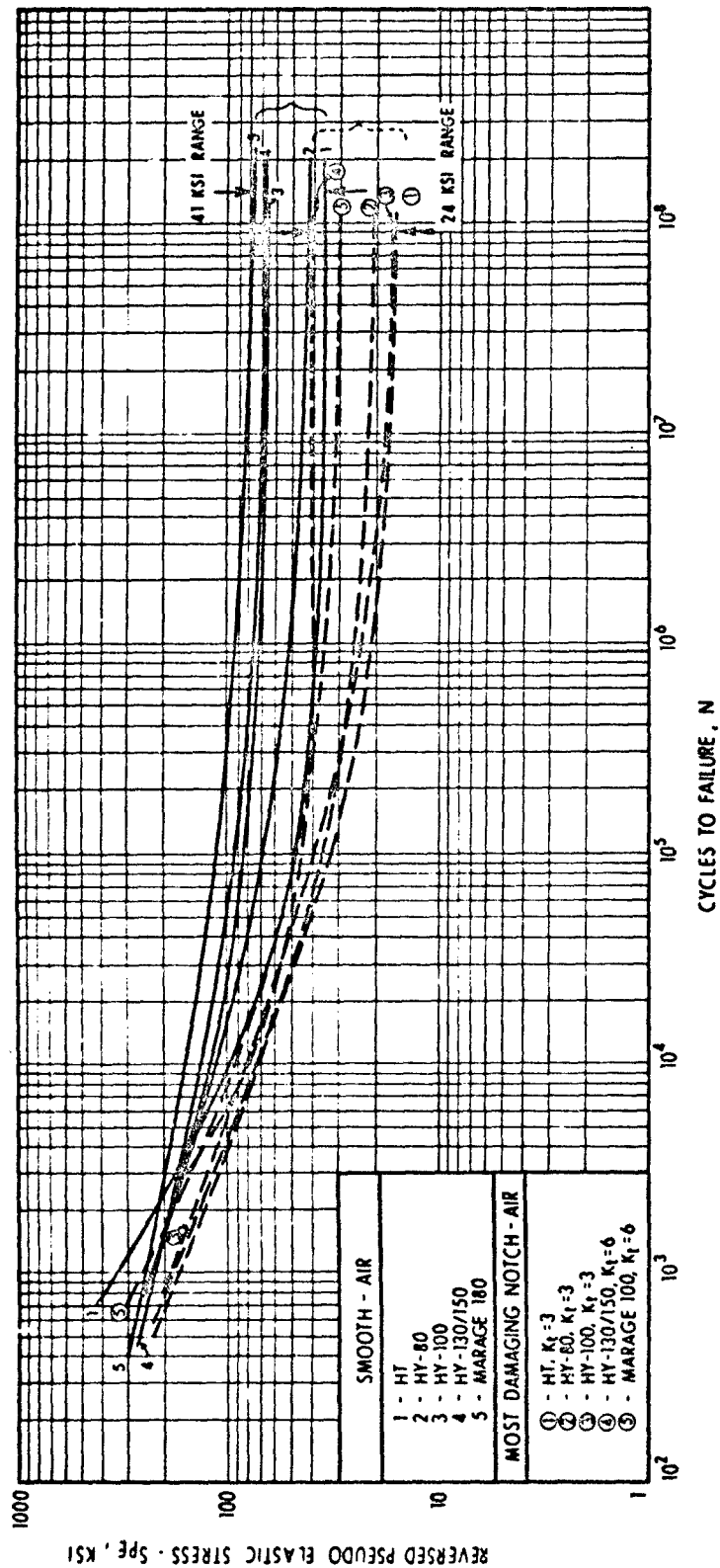


Figure 6  
Effect of Salt Water on Steels

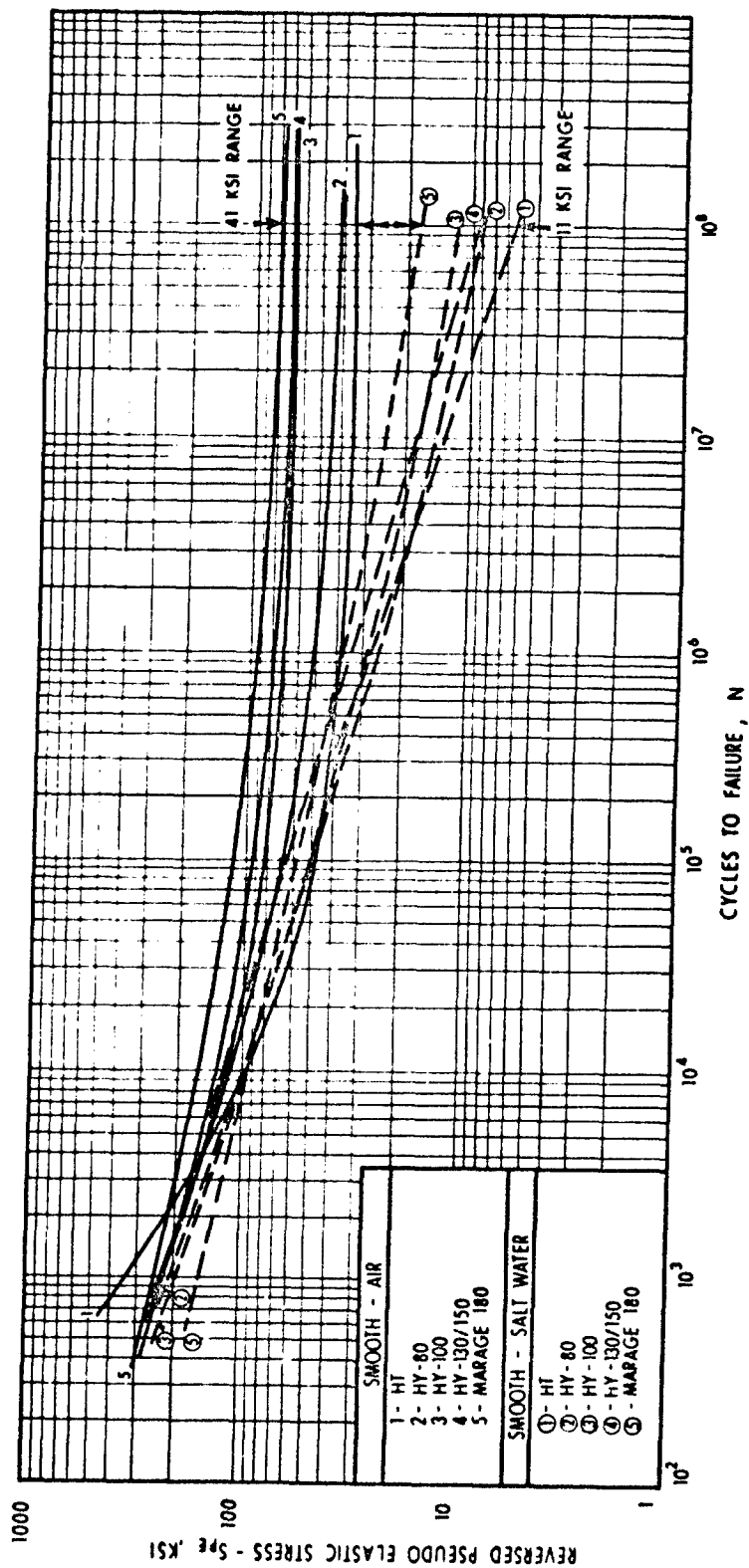


Figure 7  
Combined Effect of Sharp Notches and Salt Water on Steels

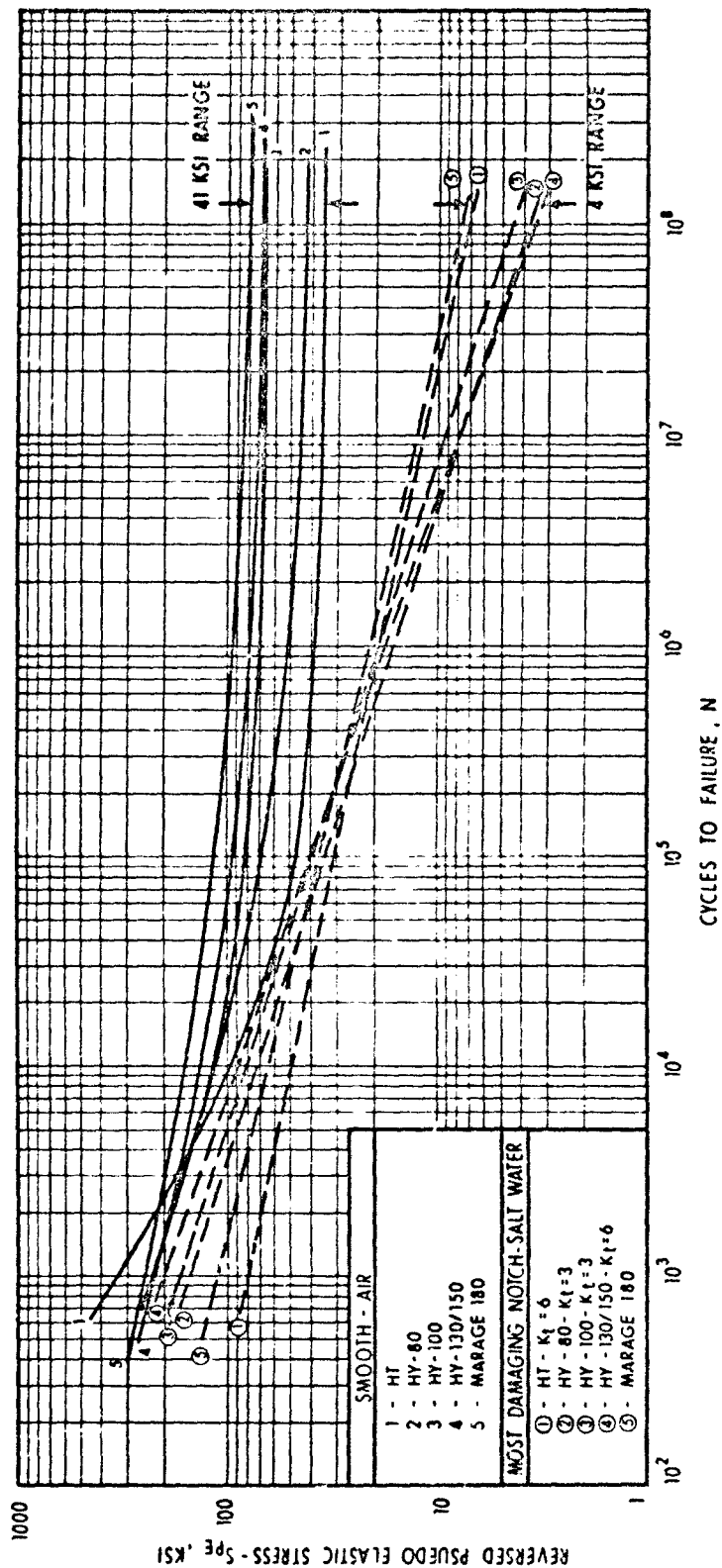


Figure 8  
 $K_t$  vs Fatigue Strength at  $10^8$  Cycles

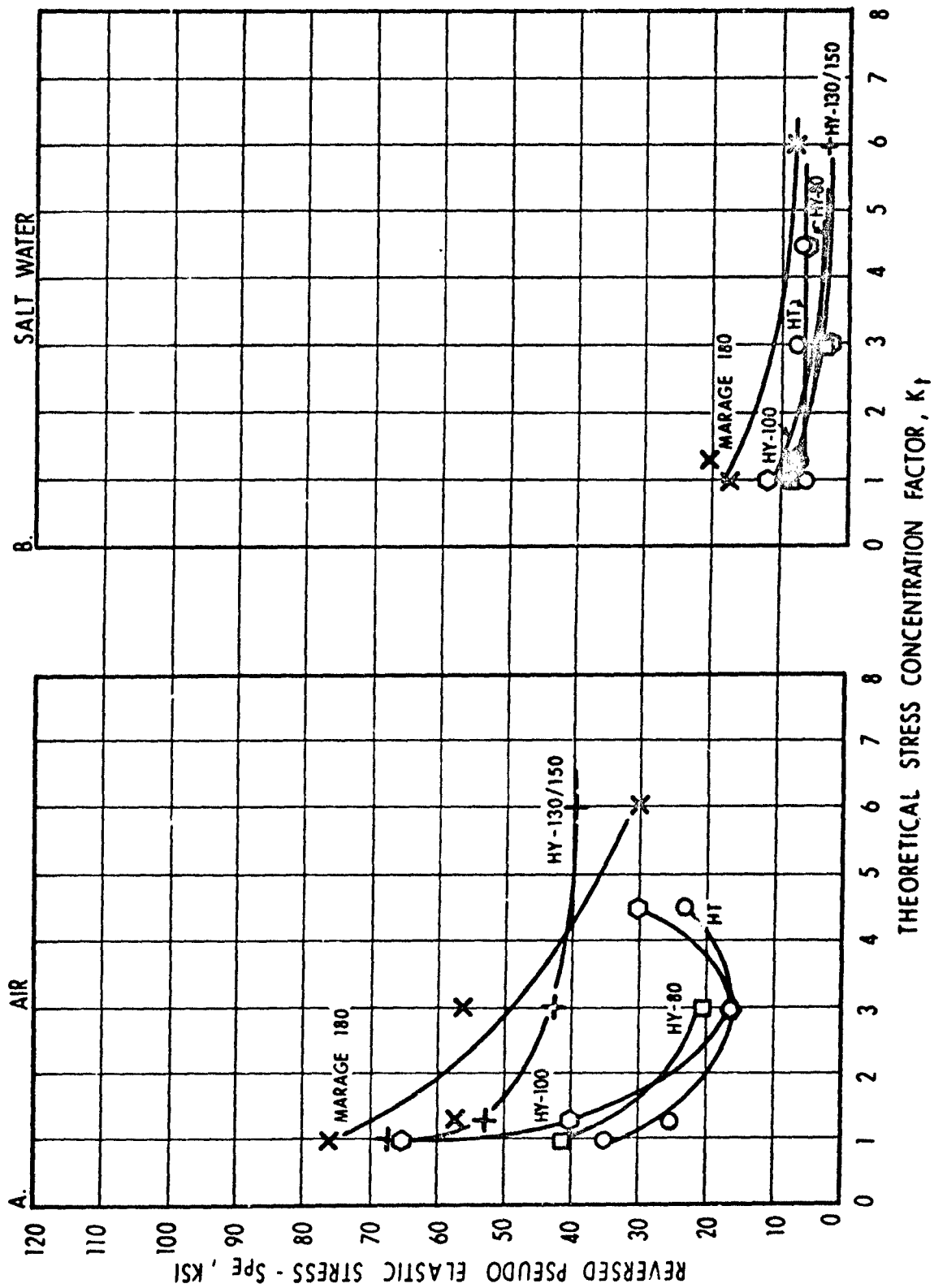


Figure 9  
Fatigue Strength Reduction by Notches and Salt Water, HT Steel

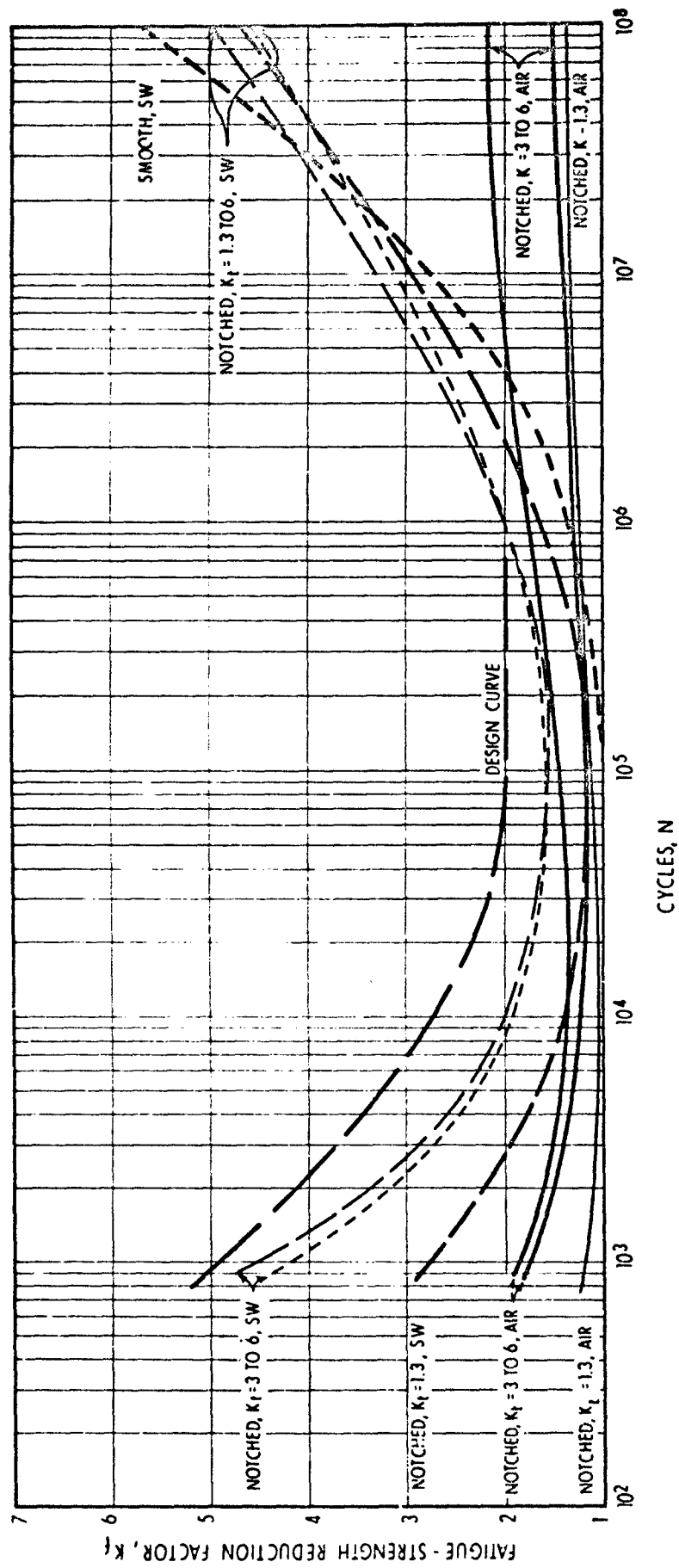
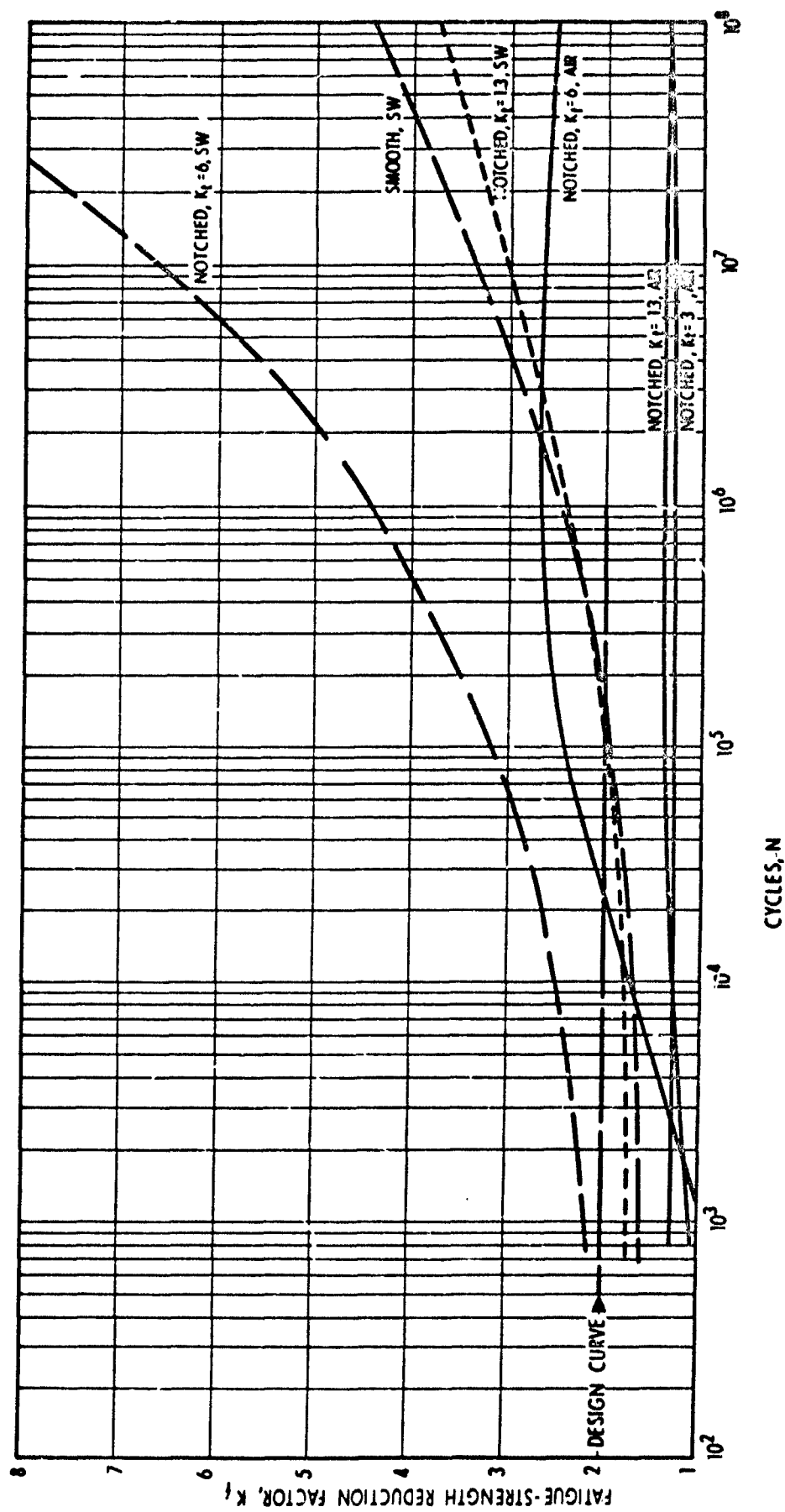
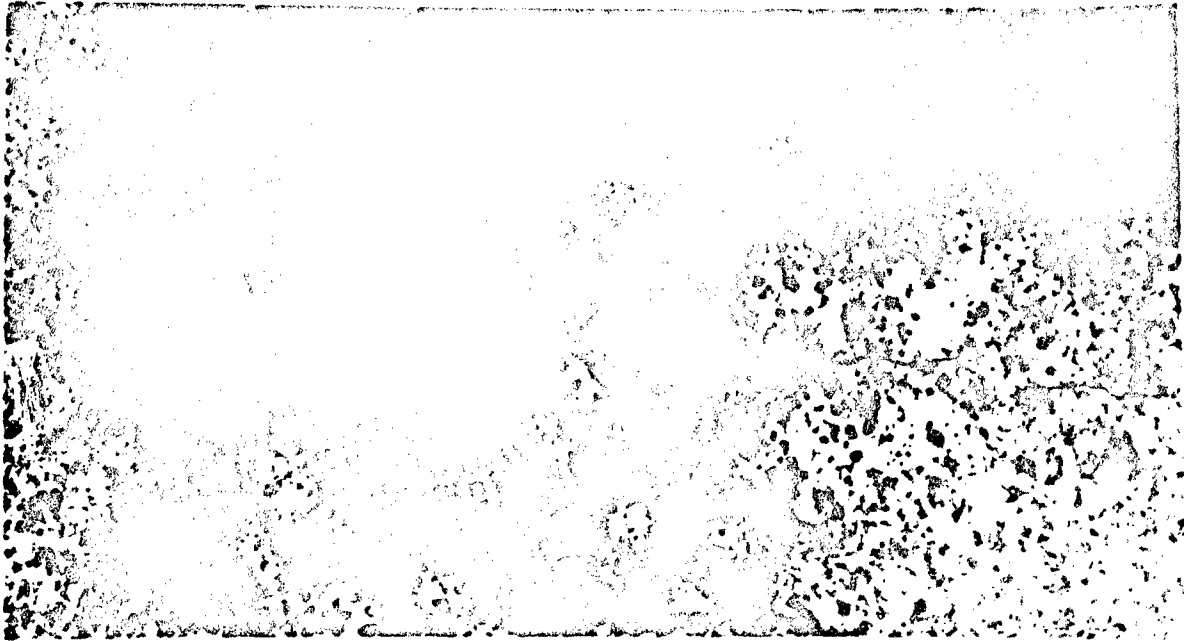


Figure 10  
Fatigue-Strength Reduction by Notches and Salt Water, Marage 180



Item (a) - 0.2-Inch Radius Notch,  $K_t = 1.3$   
 $S_{PE} = 59,400$  PSI or 144 Percent of Tensile Yield Strength  
Cycles to Failure = 14,574 at 1 CPM  
Time in Salt Water = 10 Days



Item (b) - 0.002-Inch Radius Notch,  $K_t = 1.3$   
 $S_{PE} = 33,000$  PSI or 80 Percent of Tensile Yield Strength  
Removed from Test After 11,250 Cycles at 0.02 CPM  
Time in Salt Water = 1 Year

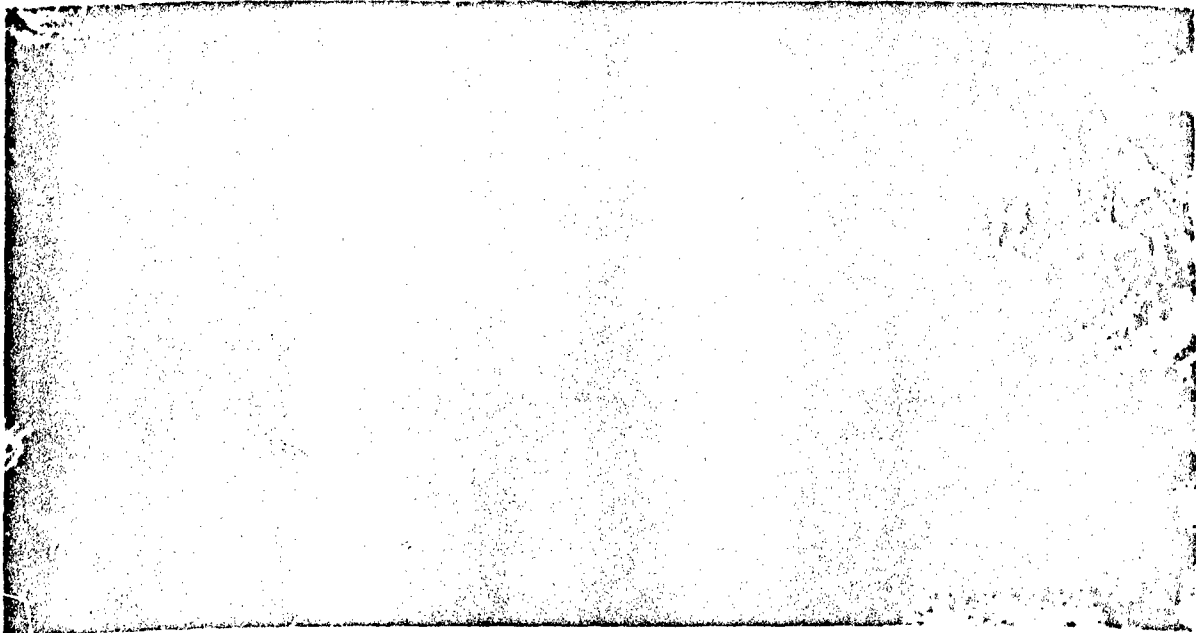
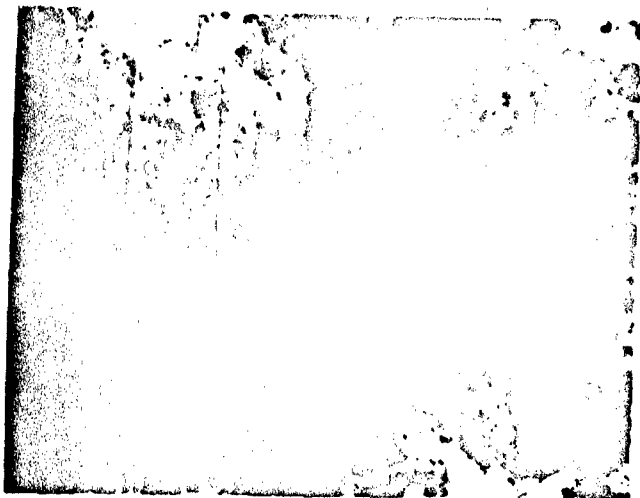
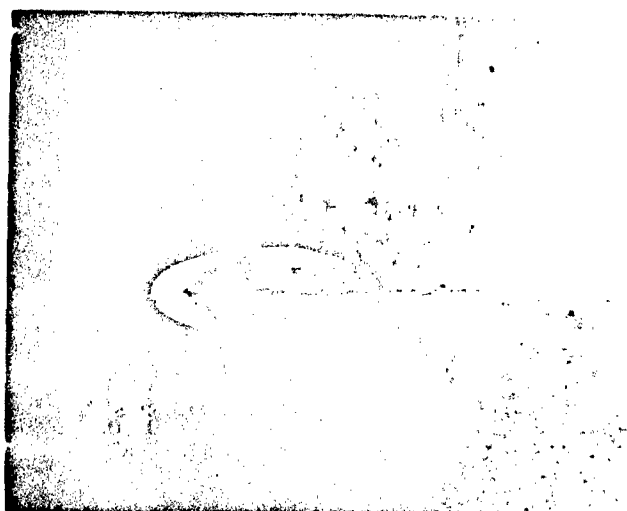


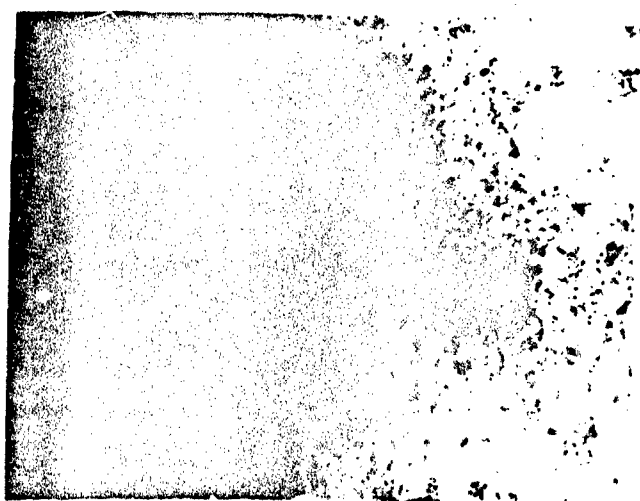
Figure 11  
Low-Cycle Corrosion-Fatigue Failures, HT Steel, 3X



Item (a)  
 Smooth (No Notch)  
 $S_{PE} = 120,000$  PSI or  
 83 Percent of Tensile  
 Yield Strength  
 Cycles to Failure = 6,926 at  
 0.3 CPM  
 Time in Salt Water = 16 Days

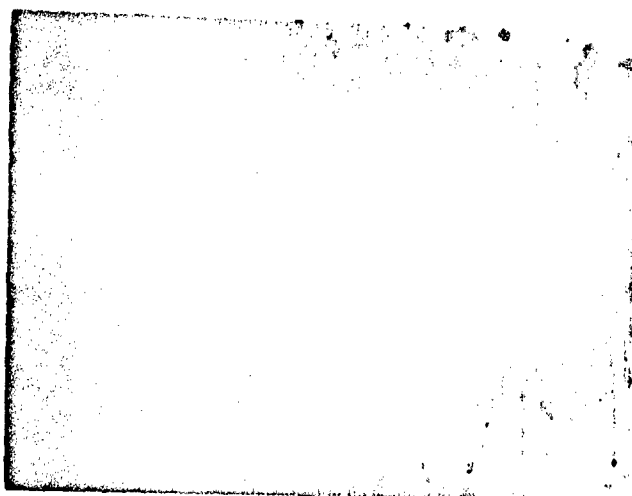


Item (b)  
 0.2-Inch Radius Notch,  
 $K_t = 1.3$   
 $S_{PE} = 96,500$  PSI or  
 67 Percent of Tensile  
 Yield Strength  
 Cycles to Failure = 12,417 at  
 0.3 CPM  
 Time in Salt Water = 29 Days



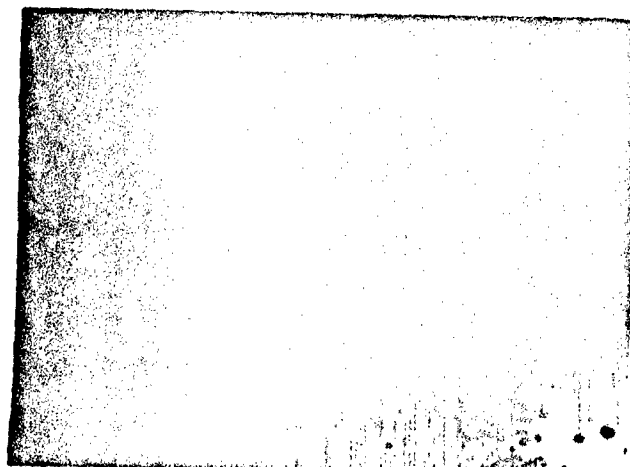
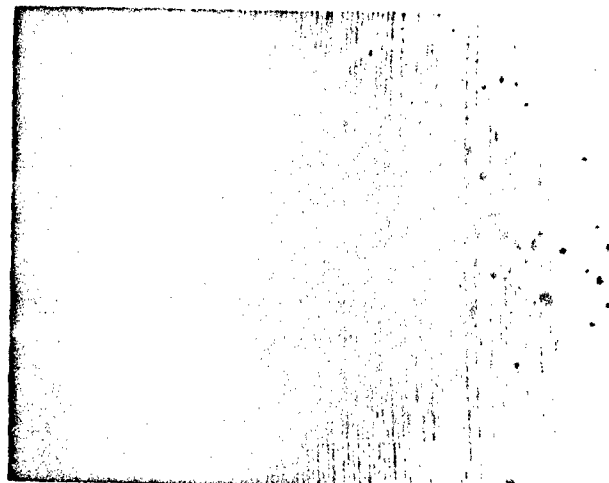
Item (c)  
 0.002-Inch Radius Notch,  
 $K_t = 6$   
 $S_{PE} = 138,000$  PSI or  
 95 Percent of Tensile  
 Yield Strength  
 Cycles to Failure = 3,111 at  
 0.3 CPM  
 Time in Salt Water = 7 Days

Figure 12  
 Low-Cycle Corrosion-Fatigue Failures, HY-130/150, 3X



Item (a)  
Smooth (No Notch)  
 $S_{PE} = 159,600$  PSI or  
80 Percent of Tensile  
Yield Strength  
Cycles to Failure = 875 at  
0.25 CPM  
Time in Salt Water = 2 1/2  
Days

Item (b)  
0.2-Inch Radius Notch,  
 $K_t = 1.3$   
 $S_{PE} = 205,200$  PSI or  
104 Percent of Tensile  
Yield Strength  
Cycles to Failure = 621 at  
0.25 CPM  
Time in Salt Water = 2 Days



Item (c)  
0.002-Inch Radius Notch,  
 $K_t = 6$   
 $S_{PE} = 154,000$  PSI or  
78 Percent of Tensile  
Yield Strength  
Cycles to Failure = 759 at  
0.25 CPM  
Time in Salt Water = 1 1/3  
Days

Figure 13  
Low-Cycle Corrosion-Fatigue Failures, Marage 180, 3X

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13. ABSTRACT

The flexural fatigue behavior of five constructional steels was investigated in air and salt water over a broad life spectrum ranging from 1000 to 100 million cycles. The yield strengths of the steels ranged from 40 to 200 thousand pounds per square inch (ksi). The effects of notches having theoretical stress concentrations ranging from 1.3 to 6 were included in this study. General conclusions are: (1) both mechanical notches and saltwater corrosion are more damaging in high-cycle fatigue; (2) the combined effect of mechanical notches and salt water is greater than either operating independently; (3) the high-cycle saltwater corrosion-fatigue strengths of sharply notched low and intermediate alloy steels are less than 10 ksi beyond 10-million cycles, regardless of the tensile yield strength level. Additional conclusions relative to notch root radius, corrosion characteristics of the steels, and fatigue design curves are presented.

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